BRITISH WELDING * RESEARCH ASSOCIATION

VOL. 4. AUGUST, 1950 No. 4

WELDING RESEARCH

PRICE FIVE SHILLINGS

Published by

THE BRITISH WELDING RESEARCH ASSOCIATION · 29 PARK CRESCENT · LONDON · W.1

Welding Research

Vol. 4 AUGUST 1950 No. 4

Published by
THE
BRITISH WELDING RESEARCH ASSOCIATION
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Association Notes

"The Welding of Thick Aluminium Alloy Plates by the Argon Arc Process"

Argon arc welding equipment designed for operation with welding currents up to 600 amps. has been developed, together with suitable electrically controlled manipulating gear to enable mechanical (automatic) welding of longitudinal and circumferential seams. Welding technique for A.W.10 alloy has been developed to produce welds in plate up to $\frac{3}{4}$ in. thick which, after heat-treatment, give tensile properties equal to those of the parent plate, apart from a reduced percentage elongation. The problems involved in production of a pressure-tight circumferential seam are discussed and the progress made towards their solution indicated.

"Some Extracted Notes on Hastelloy Fabrication and Welding"

The material for this report was originally prepared by the Development and Liaison Department in answer to a Member's query. It is thought, however, that the information would be of general interest.

Hastelloy high-strength nickel-base alloys are a series of four alloys, designated by the letters A, B, C and D, and have been developed to stand severe chemical corrosion. They are available as castings, standard mill forms and welding rod and can be fabricated into chemical equipment such as tanks, autoclaves, heat exchangers and coils, etc. A table is given showing principal welding features of Hastelloy alloys.

New Members

The following new members have been elected:—

British Transport Commission.
Thos. Broadbent & Sons Ltd.
Cleveland Bridge & Engineering Co. Ltd.
Coras Iompair Eireann.
Folland Aircraft Ltd.
Siemens-Schuckert (Great Britain) Ltd.
Widnes Foundry & Engineering Co. Ltd.

B.W.R.A. Fifth Annual General Meeting

The Fifth Annual General Meeting of the Association was held at the Research Station, Abington, near Cambridge, on Thursday, 13th July, 1950, when the Report of the Council, statement of accounts for the year to 31st March, 1950, and Balance Sheets as at 31st March, 1950, were received and adopted. Dr. J. H. Paterson, introducing the report, expressed the Council's satisfaction with the progress of researches; the new work undertaken by the Research Board during the year had already proved its value, and as the laboratory facilities and equipment increased, so the Association's contribution to the welfare of the Welding Industry and to the nation's industries as a whole would be a very substantial one.

The Liaison Department had been reorganised and placed on a firm footing; the belief of the Council that it would usefully supplement the work of the Association by bringing the results of its work to bear directly on Members' problems had been fully justified.

The Council was anxious to obtain the most modern

types of testing plant vital to its work and recorded with pleasure that a pulsating pressure testing plant, for fatigue testing pressure vessels, had been installed and a large tensile testing machine had been placed on order. These large and expensive equipments, however, demanded considerable laboratory space, and the Council was therefore planning to build a fatigue testing laboratory at Abington, thus releasing a portion of the old laboratories for much-needed expansion of other work. This new laboratory would cost in the neighbourhood of £20,000—a sum much beyond the amount which the Association could spare from its reserves, and an appeal for support would have to be made. The Chairman expressed the hope that members would consider what they could do to help in the building of this laboratory and in increasing the membership of the Association.

The Chairman recorded the Council's high appreciation of the work done by the Research Board and members of the various committees, and also of the quality and high standard of the work of the Director and Staff. He announced that Sir Stanley V. Goodall, K.C.B., O.B.E., had consented to be Vice-President and welcomed Sir Charles Lillicrap, K.C.B., who would be the new Chairman of the Council.

At the termination of the meeting, parties were escorted round the laboratories, where members of the staff demonstrated the apparatus and researches in progress.

Have you got your copy of:—

SPOT WELDING CALCULATOR

A sliding scale calculator giving minimum electrode pressure, tip diameter, minimum edge distance, weld current and weld time for thicknesses of mild steel sheet varying from .01 in. to .25 in.

Price 1/6, post free.

RECOMMENDATIONS FOR THE DESIGN AND FABRICATION OF ARC WELDED STRUCTURAL STEELWORK. BUILT-UP GIRDERS AND COMPRESSION MEMBERS

This memorandum is intended to provide guidance on the design, fabrication and erection of arc welded structural steelwork. The recommendations have been drawn up after a detailed study of existing practice. *Price 1/6, post free.*

RECOMMENDED PRACTICE FOR THE SPOT WELDING OF LOW CARBON MILD STEEL SHEET

This booklet covers recommended spot weld dimensions, electrodes, welding pressure, welding time, welding current, forging time, fluctuations in the value of the variables, weld pitch, weld strength, edge distance, etc. A table of recommended settings is given. *Price 1/6, post free.*

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The Welding of Thick Aluminium Alloy Plates by the Argon Arc Process

By J. E. CHARD, B.Sc.(Eng.), A.R.S.M., A.I.M., and N. MACDONALD

(Royal Naval Scientific Service)

SUMMARY

Argon arc welding equipment designed for operation with welding currents up to 600 amps. has been developed, together with suitable electrically controlled manipulating gear to enable mechanical (automatic) welding of longitudinal and circumferential seams. Welding technique for A.W.10 alloy has been developed to produce welds in plate up to ½ in. thick which, after heat-treatment, give tensile properties equal to those of the parent plate, apart from a reduced percentage elongation. The problems involved in production of a pressure-tight circumferential seam are discussed and the progress made towards their solution indicated.

1. INTRODUCTION

Arising from an Admiralty requirement for a high strength pressure vessel of welded aluminium alloy construction, development work has been carried out to establish the most suitable process and the necessary special technique for producing high efficiency welds in aluminium alloy plate of thicknesses up to ½ in. The alloy selected was STA.7/A.W.10 (B.S.1470: 1948—H.S.10) and work has been directed to producing welds using a filler rod of similar composition to the parent plate with a view to developing maximum strength by heat treatment after welding, and also to avoid the dangers of electrolytic corrosion. On test plates of ¼ in. and ½ in. thickness, it has been possible to produce consistently welds showing a 0·1 per cent. proof stress value of 16-17 tons per sq. in. with an ultimate tensile strength of upwards of 20 tons per sq. in., with 4 to 5 per cent. elongation. A considerable amount of preliminary work has also been done on the production of small experimental pressure vessels, but some problems still remain to be solved.

Some experimental work was carried out into the possibilities of applying gas welding (oxy-acetylene and oxy-hydrogen) for the purpose, but the results were not very promising and there was a pronounced tendency to cracking of the weld. The metallic arc welding process was found to give much better results and welded test plates having excellent properties were produced. There were, however, obvious disadvantages of this process in the production of actual welded containers owing to the relatively short run obtainable from a given electrode (with the necessity for chipping out of slag before recommencing to weld), while the process suffered, in common with gas welding, from the danger of possible flux entrapment in the weld. Following this preliminary work, it was decided that the argon arc process offered the most promise of success, and effort has been concentrated on the development of this process.

When it was decided to concentrate on the argon arc process for this application, no commercial equipment was available in this country suitable for welding plate thicker than about 3/16 in. using an air-cooled torch. Consequently, action was taken to design and make a water-cooled torch which enabled welding currents up to about 300 amps. to be employed—i.e., of sufficient power to enable plates up to ¼ in. thickness to be welded successfully with a single pass. Following the promising results obtained during this preliminary stage of the work, it was decided in May, 1949, that it would be necessary to have equipment capable of a maximum welding current of about 600 amps to enable the work to be extended to plates of ½ in. thickness. A suitable torch was therefore designed and made, and the necessary electrical installation provided, the new equipment being brought into operation in September, 1949. At the same time, it was decided that to ensure reproducible welds (both longitudinal and circumferential), it was most desirable to arrange for some form of mechanical or automatic welding and an old lathe was adapted for this purpose and provided with suitable electric controls, both for movement of the job relative to the welding head and also for mechanical feeding of the filler wire. Automatic control of the argon supply was also provided to ensure the utmost economy. This manipulating equipment was brought into use about the same time as the higher capacity welding set.

2. DEVELOPMENT OF EQUIPMENT

(a) Torch Design

The original 300-amp. water-cooled torch designed and made in the Establishment employed a water-cooled handle and electrode holder with a refractory argon shield. It was found that the refractory shields commercially available at the time did not withstand operating conditions for an acceptably long period and the design was therefore modified to employ a cylindrical shield of fused silica. These silica sheaths were readily made by cutting lengths of fused silica tubing and they were held in position in the torch by two pins engaging in grooves ground in the external surface of the silica sheath. This arrangement proved quite satisfactory and the fused silica sheaths gave a much longer life. Commercially available electrolytic condensers and high frequency spark gap equipment were employed. When it was decided to proceed with the design of a torch capable of handling 600 amps., the opportunity was taken for a complete redesign embodying some features to facilitate production. The new torch contained no refractory components, the argon shield being made of water-cooled copper insulated from the torch body by a machined sleeve made from ebonite, the design being so arranged that this was not subjected to any heat. The water cooling for the copper argon shield passed through short rubber pipes from the torch head, these providing the necessary insulation. Fig. 1 shows the general arrangement of the torch, which has proved entirely satisfactory with welding currents up to 600 amps. Provision was made for the use of tungsten electrodes up to 7/16 in. diameter, smaller electrodes being catered for by means of suitable collets. As anticipated, a tungsten electrode of ¼ in. diameter has proved adequate for carrying welding currents up to 570 amps. without becoming unduly overloaded and a welding current of this order has been found adequate for producing single pass welds in ¼ in. plate.

One advantage of employing a water-cooled copper argon shield was that it was possible by simple machining operations to vary the internal shape and dimensions of the shield, and some work has been carried out with a view to establishing the most efficient form of hood from the point of view of producing clean welds with the minimum argon consumption. It has been possible to produce satisfactory welds in ¼ in. thick plate at a current of about 320 amps. (using a 7/32 in. diameter electrode) with an argon consumption down to 6 litres per minute, and in ¼ in. thick plate with welding currents of about 530 amps. (using a ¼ in. diameter electrode) with an argon consumption of 12 litres per minute. It is hoped that the latter figure may still be improved upon by modified shield design. It is, however, too early to say whether much advantage is obtainable from a specially shaped shield.

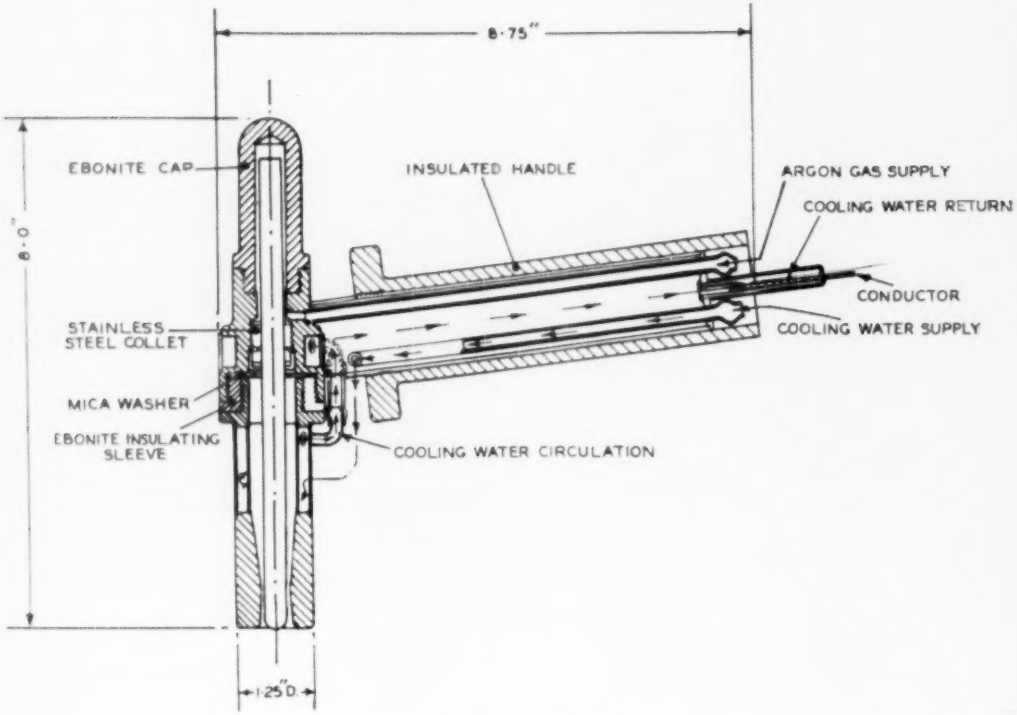

Fig. 1. Argon arc welding torch design.

The type of argon shield employed experimentally was on the lines of a convergent-divergent nozzle, as it was thought that this offered the possibility of producing a more stable argon flow at low consumption than would be possible with a simple parallel hood. It was found that the angle of the cone was fairly critical, as was also the position of the end of the electrode relative to the mouth of the shield. One interesting phenomenon which was experienced with one design of hood was that at the end of welding, as the electrode cooled below approximately 1000 deg. C., a dense white fume was evolved which continued until the temperature of the electrode had fallen to approximately 800 deg. C., when it abruptly ceased. This was at first puzzling, but was traced to oxidation of the tungsten, the fume being found to be over 90 per cent. tungstic oxide. The source of the oxidising atmosphere producing this fume was at first suspected to be contamination of the argon, but it was eventually proved to be due to entrained atmospheric air being drawn in at the mouth of the hood. During welding, the high temperature of the arc presumably caused sufficient expansion of the argon to avoid such introduction of air, but, on cooling down after welding, this expansion effect no longer operated, with the result that oxidation commenced. Slight modification of the cone angle of the shield completely cured this trouble. Any turbulence in the argon flow will, of course, also tend to produce oxidation of the weld itself.

(b) Manipulating Equipment and Controls

It was possible to obtain an old lathe, scheduled for scrapping, which proved eminently suitable for conversion to a manipulator. The lathe was provided with variable cone pulleys, as well as a fast and low-speed gear change, which enabled a wide range of speeds to be obtained both for rotation of the chuck (for circumferential welds) and movement of the saddle (for longitudinal welds). The lathe was driven through a high ratio reduction gear from a small electric motor. To provide ease of control, it was decided to employ direct current, and a small redundant 1 H.P. motor generator set was installed which provided a supply at 110 volts D.C. This was used for the manipulator drive and also, through a suitable resistance, for operating the wire feed motor and the automatic argon supply valve. Variable electric speed controls for the manipulator movement and also for the wire feed motor were mounted on a small panel coupled to the machine by a flexible lead, so that the controls could be placed in the most convenient position for the operator for both circumferential and longitudinal welding. Figs. 2 and 3 show general views of the machine and electrical equipment. Fig. 5 shows the control panel in more detail. The left-hand speed control governs the manipulator, while the small knob on the right governs the rate of wire feed. The operation of the switch seen in the centre of the control panel turns on the argon supply to the preset value for welding, move-

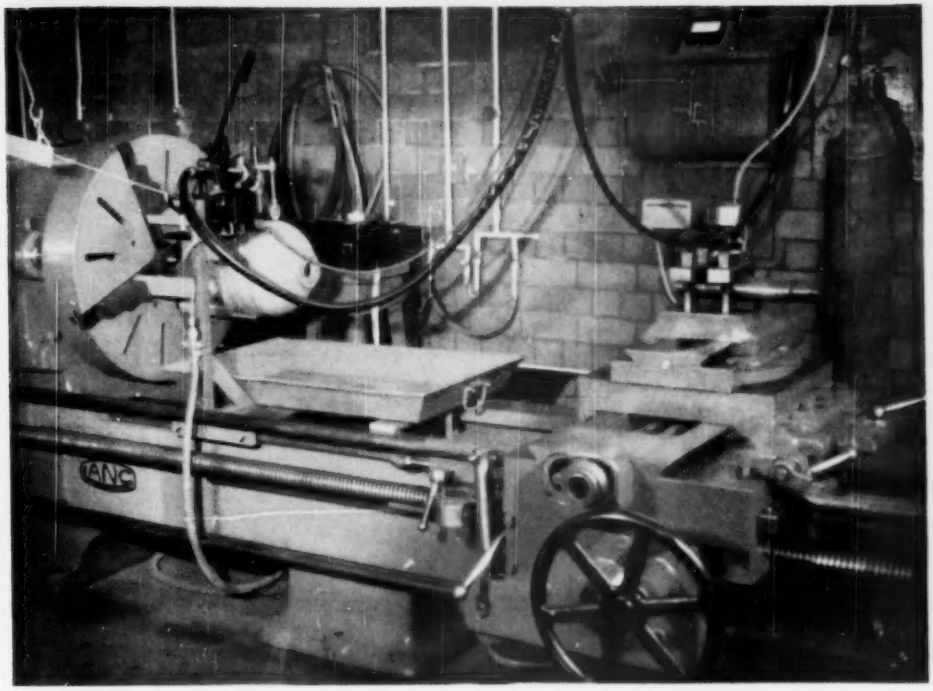

Fig. 2. General view of welding machine.

ment of the valve operating a red indicator light (seen on the left at the back of the control panel). At the completion of welding, switching off this switch stops the manipulator, but by means of a suitable thermal delay unit, the argon is maintained at full flow for a further predetermined period to enable the welding arc to be maintained, if desired, for a short period after the machine is stopped and to initiate cooling down of the tungsten after welding is completed. At the end of this period, the argon supply is automatically cut down to a low figure (3 litres per minute), which is adequate to prevent oxidation of the tungsten during cooling, and this lower rate of flow is maintained for a further pre-set period, after which the argon is automatically shut off. The lower rate of flow is indicated by the right hand (amber) indicator lamp on the back of the control panel). Fig. 4 shows the electric argon control valve and (on the left) the thermal delay unit. Figs. 6 and 7 respectively show the machine set up for circumferential and longitudinal welds. It will be seen that the torch is designed to run with rollers on the actual job to ensure a constant arc length, and to compensate for any slight irregularity or ovality in the surface, and is capable of being lifted by means of a cam by a lever at the top. At the conclusion of welding, the torch is raised by operation of this lever and the welding arc broken. Starting of the welding arc is effected by the use of a small carbon wedge introduced under the tungsten electrode.

Water supply for cooling the torch is taken through a suitable orifice which ensures the correct rate of flow without the necessity for any adjustment of the supply valve. The back pressure from this orifice operates a suitable water interlock (seen in Fig. 3), which prevents the main welding current being switched on unless the water supply is flowing. The cooling water passes over a suitable fuse to provide protection in the event of failure of the mains supply.

(c) Welding Current

Owing to the fact that a 600-amp. welding transformer was not available, it was necessary to connect in parallel two 300-amp. transformers of similar design, each provided with a suitable bank of electrolytic condensers. By employing one or both of these transformers, it is possible to obtain a range of welding currents up to 600 amps.

(d) Welding Rate

The rate of welding is dependent upon the current employed and the dimensions of the work piece. In making single-run welds in $\frac{1}{2}$ in. thick test plates with a current of 530 amps., a rate of 4 in. per minute has been found satisfactory. A similar speed is suitable for single-run welds in $\frac{1}{2}$-in. plate at a current of 320 amps, but faster rates are obtainable by the use of an increased welding current. (Test plates employed were 24 by 7 in.)

3. WELDING TECHNIQUE

The investigations by the Aluminium Development Association Team at Birmingham University* confirmed that A.W. 10 alloy was very prone to weld cracking, and it was realised that considerable

* P. H. Jennings, A. R. E. Singer and W. I. Pumphrey, J. Inst. Metals, 1948, 74 (5), 227.

Fig. 3. Electrical equipment.

development of technique would be necessary if success was to be achieved with this alloy, particularly when welded with a filler rod of similar composition and in the case of plates of relatively great thickness.

The preliminary work carried out with gas welding and metallic arc welding showed that if plates to be welded were preheated appreciably above 150 deg. C., there was a great liability for cracking to develop through the centre of the weld. Provided, on the other hand, the preheat temperature was kept below this figure, cracking of the weld did not present a difficulty. This conclusion has been confirmed by subsequent work with the argon arc process. While in the case of thin plates, it is advantageous to work without preheat, in the case of thicker plates (above $\frac{1}{4}$ in.) a light preheat is desirable to facilitate proper fusion at the commencement of welding and to accelerate the welding rate.

At first a 60 deg. "V" preparation was employed in the case of plates of $\frac{1}{4}$ in. thickness, but difficulty was experienced due to a tendency for oxide entrapment on the fusion faces. This tendency was found to be materially reduced if no preparation was employed and the plates were butted together as closely as possible for welding. This technique has been found successful also in the case of $\frac{1}{2}$ in. thick plates in which satisfactory welds are produced by butting the edges together without any "V" preparation. On the other hand, some satisfactory welds have been produced with $\frac{1}{2}$ in. plate in which there was a small "V" preparation extending about $\frac{1}{4}$ in. deep (i.e., with $\frac{1}{4}$ in. root face). There is, however, no advantage from this preparation provided adequate power is available and simple butting of the edges to be welded has been adopted as standard. At first, great care was taken to clean the surfaces to be welded by pickling and/or scratch brushing, but it has been found that, provided a reasonable standard of cleanliness is observed (i.e., degreasing), such precautions are not essential and, experimentally, surprisingly satisfactory welds have been produced from scrap plates welded without any preliminary cleaning whatever.

In the early work on thick ($\frac{1}{2}$ in.) plates, considerable difficulty was experienced due to traces of oxide left in the root of the weld. It was found advantageous to employ a grooved steel backing strip to support the weld as this assisted the displacement of any such traces of oxide into the groove and out of the weld proper. There were the further advantages that the efficiency of fusion could be readily judged by observing, after welding, whether the groove in the backing strip had been completely filled, giving a continuous rib, while the latter resulted in an increased cross section of weld, constituting an appreciable reinforcement of section. In the case of thick plates, with hand operation of the torch it was difficult to ensure that the arc was directed uniformly to the edges of both plates, with the result that sometimes there was a tendency for lack of proper fusion at the root on one or other of the plates. It was this consideration which chiefly determined the decision to construct a machine for mechanical or automatic welding in order that the torch could be set accurately with reference to the plates to be joined.

Considerable trouble was experienced from time to time due to the erratic behaviour of the arc which deflected to a marked degree to one side or the other of the seam, sometimes for a considerable distance, in mechanical welding. This was very serious as proper fusion of the two plates was not, of course, obtained. After a considerable amount of experimental work, this trouble was traced to a magnetic effect associated with the return path of the current to earth relative to the position of the arc. Any arrangement giving a current carrying loop in the line of the weld resulted in

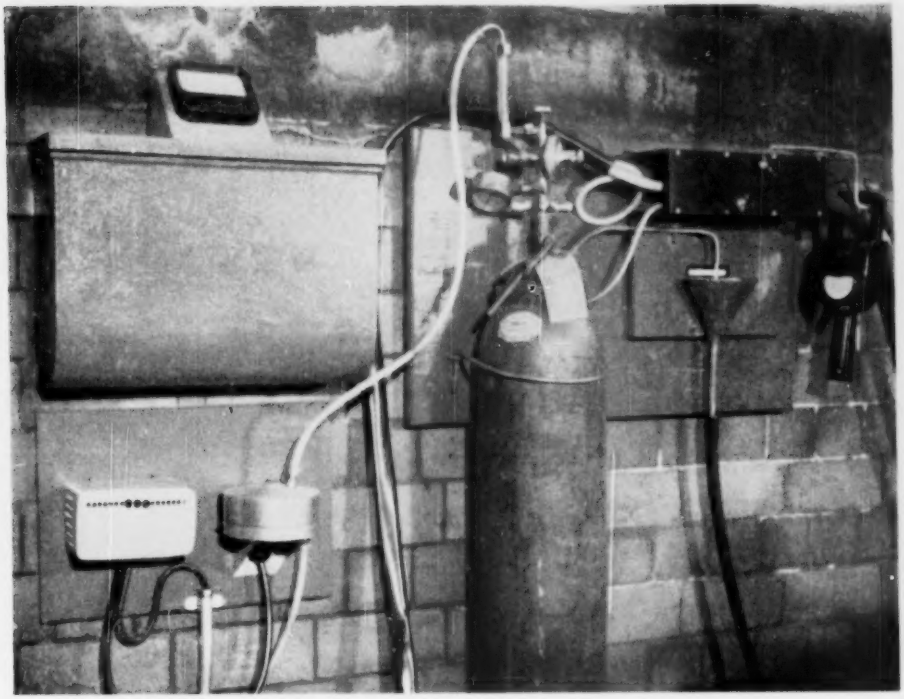

Fig. 4. Argon control valves, thermal relay, clip-on ammeter (*right*) and voltmeter (*left*).

deflection of the arc, and it was found possible to produce deflection in either direction by suitable positioning of the earth cable and clamps. By careful positioning of the earth clamps on the work, it was possible to overcome this effect.

A few experiments have been carried out to establish the optimum heat treatment for welded plates with a view to developing the required mechanical properties. It was at first thought that owing to the fact that the weld was a cast structure and that the adjoining parent plate would be over-precipitated due to the heat of welding, a prolonged period (e.g., 4 hours) of solution treatment would be necessary. Mechanical tests obtained on welded plates heat treated in this way gave an 0·1 per cent. proof stress value of approximately 14 to 15 tons per sq. in. with ultimate tensile strengths of 17 to 18 tons per sq. in. and 5 to 8 per cent. elongation. Subsequent work indicated that there was no advantage from a prolonged soaking time, and, in fact, improved proof stress results were obtained by keeping the solution treatment time short and increasing slightly the temperature (i.e., working at the top of the recommended temperature range—535 deg. C.). There was some indication that a rather long precipitation treatment was advantageous. The following table gives some typical mechanical properties obtained on welded plates solution treated at 535 deg. C. for three-quarters of an hour, followed by precipitation treatment at 170 deg. C. for 14 hours. (In the case of welded test plates, before tensile tests were carried out, the metal was milled down on both faces to remove any reinforcement of section and to ensure a parallel test plate, the minimum possible amount of metal being removed to ensure this.)

Specimen No.	Thickness of Plate as Welded	Test Piece Dimensions	0·1 per cent. Proof Stress (tons per sq. in.)	Ultimate Tensile Strength (tons per sq. in.)	Elongation per cent.
AA.16-1	½ in.	·997 in. × ·307 in.	16·7	20·0	5·5
2	½ ,,	1·0 ,, × ·278 ,,	16·4	20·3	8·5
3	½ ,,	1·0 ,, × ·324 ,,	16·8	20·3	7·75
AA.14-1	½ ,,	·991 ,, × ·573 ,,	17·0	20·3	4·5
2	½ ,,	·998 ,, × ·581 ,,	17·1	20·0	4·5
B.S. 1470: H.S. 10 W.P. (Sheet and Strip) Specification Requirements ...			15 min.	19 min.	8 min.

Fig. 5. Control panel.

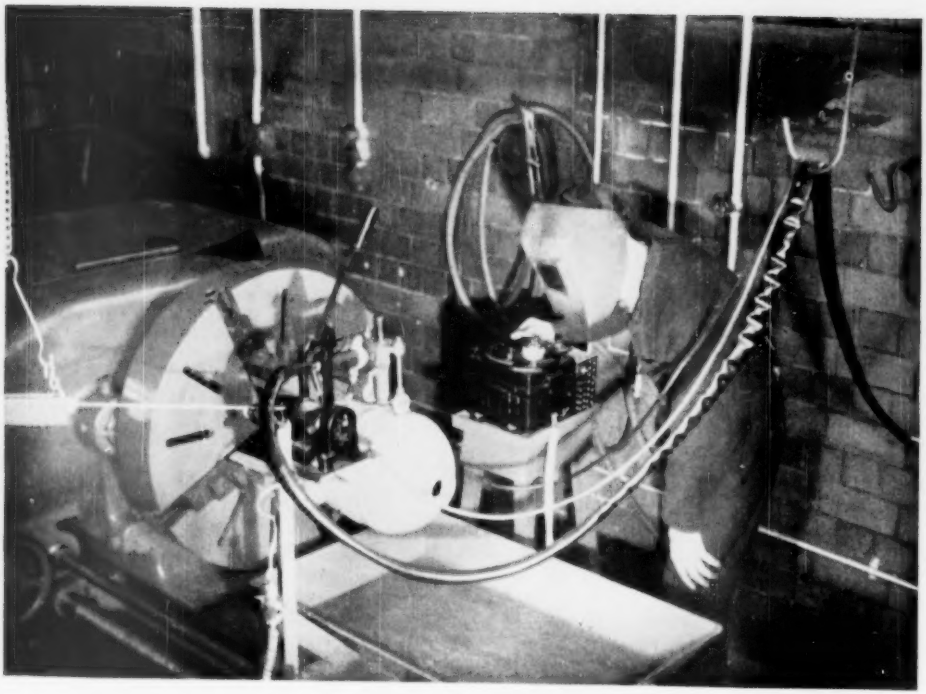

Fig. 6. Machine set up for circumferential welds.

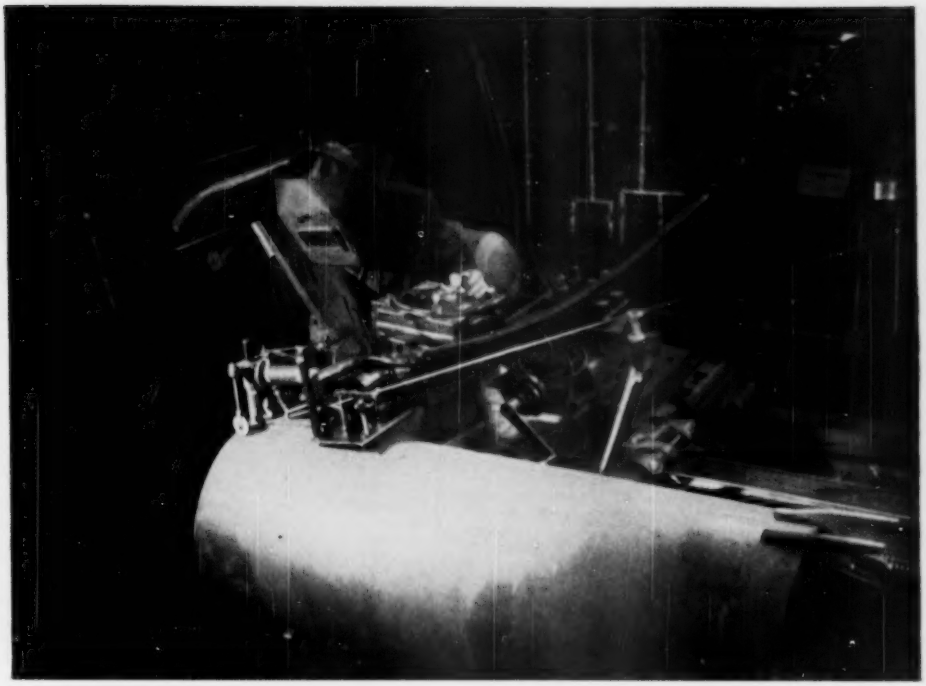

Fig. 7. Machine set up for longitudinal welds.

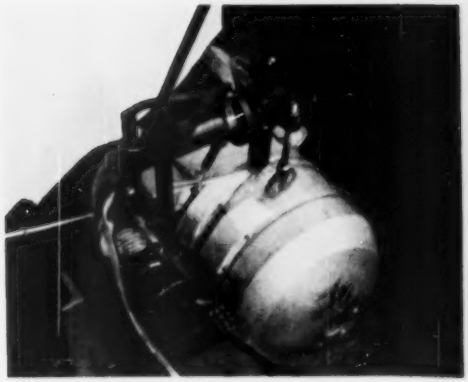

Fig. 8. "Run-out plate" and ramp assembly.

The problems involved in producing a circumferential weld in a vessel are different from, and greater than, those in the production of a satisfactory longitudinal weld between two plates. In particular, there is the difficulty of heat build-up as the end of the weld is reached and, finally, the problem of ending the weld without production of a crack, particularly as there will inevitably be a crater crack where the weld is stopped. Consequently, at a fairly early stage in the development a number of small pressed cups (11 in. external diameter) of A.W.10 alloy were made, having a wall thickness which could be machined either to $\frac{1}{4}$ in. or $\frac{1}{2}$ in. to enable actual experience to be gained on the problems of producing a circumferential weld and to provide a basis for full-scale work. It was found possible to produce circumferential welds on these small bottles having a very good and uniform appearance and satisfactory penetration, but in every case there was a small crack at the position in which the weld stopped. This crack caused failure of the bottles under pressure test by leaking, although pressures up to 2000 lbs. per sq. in. did not reveal any serious structural weakness of the weld itself.

It was considered that this terminal crack was essentially a shrinkage crack, resulting from the fact that the last molten metal deposited was not "fed", and some attempts were made to build up a small "feeding head" with weld metal at the end of the run to overcome this difficulty by torch manipulation. This did not, however, prove successful. A few experiments were conducted in an attempt to provide an actual refractory lined feeding head at the end of welding which was filled with molten metal from a crucible, but this proved cumbersome and not very satisfactory.

Following the lines indicated by the work of the Welding Research Team at Birmingham University, one or two welds were carried out with a filler rod of modified composition (i.e., with somewhat higher silicon and magnesium content than the parent plate) with a view to producing a weld deposit of lower tendency to cracking. The modified composition filler rod appeared on visual examination to have resulted in an improvement, there being no visible crack. However, on pressure test, the bottle leaked and closer examination of the weld revealed the presence of fine cracks. Consideration was also given to employing a double run technique, as it was thought that the smaller volume of liquid metal present at the end of the run in this case would be beneficial.

A possible solution was recently evolved employing a tapered run-out plate (shown in Fig. 8). As will be seen, the run-out plate has a thin-pointed end carrying a groove into which the filler wire fits as the rotation of the bottle brings the run-out plate under the torch. As soon as the tip of the run-out plate starts to fuse, thus providing filler metal, the filler wire is withdrawn and the arc fuses a progressively greater quantity of metal from the run-out plate, while being raised above the level of the bottle as one of the wheels carrying the torch runs up the ramp attached to the run-out plate. This method has resulted in the satisfactory feeding of the end of the weld and three bottles having a wall thickness of $\frac{1}{2}$ in. were welded in this way in succession which were completely pressure tight up to pressures of 2,300, 2,400 and 2,600 lbs. per sq. in. respectively. (These figures compare with the calculated pressure for yield of 2,350 lbs. per sq. in., based on an 0·1 per cent. proof stress value of 15 tons per sq. in.) The procedure was to commence welding as usual and to clip on the run-out plate ramp assembly while the machine was running after approximately one-quarter of the weld had been completed, so that the run-out plate covered the weld which had already been deposited. Fig. 9 shows the appearance of the run-out plate on the completion of welding.

It is thought that there may perhaps be some further advantage in employing a run-out plate of modified composition and containing a grain-refining agent with a view to providing the maximum possible soundness at the end of the weld.

Fig. 9. "Run-out plate" at conclusion of welding.

4. CONCLUSIONS

It has been shown that the construction of an efficient argon arc welding equipment for welding currents up to 600 amps., and designed for the mechanical welding of circumferential and longitudinal seams, does not present any undue difficulty and there seems every reason why this process should find increasing use for welding of aluminium and its alloys.

It has been shown that sound and reproducible welds can be made in A.W.10 plate up to $\frac{1}{2}$ in. thickness, using a filler rod of similar composition, which will give mechanical properties equal to those of the parent plate as regards proof stress and ultimate tensile strength and with acceptable ductility. (On two occasions tests showed fractures in the parent metal in preference to the weld.)

While the problems involved in production of satisfactory circumferential welds for pressure vessels in A.W.10 alloy have not yet been entirely overcome, work is proceeding on lines which, it is hoped, will provide a solution to these problems.

It is fully realised that many aspects touched on in this report require much fuller investigation, but it is hoped that it may serve a useful purpose as a basis for discussion.

5. ACKNOWLEDGMENTS

It is desired to record appreciation of the assistance and encouragement received from colleagues and also of the co-operation shown by representatives of the British Welding Research Association, the Northern Aluminium Company and the British Oxygen Company, and of Dr. West of Aluminium Development Association, and Dr. Pumphrey and Mr. Moore of Birmingham University.

The authors are indebted to the Chief of the Royal Naval Scientific Service for permission to publish this paper.

R.60

Some Extracted Notes on Hastelloy Fabrication and Welding

Hastelloy high-strength nickel-base alloys are a series of four alloys, designated by the letters A, B, C and D, that have been developed to withstand severe chemical corrosion, including the common mineral acids, such as hydrochloric and sulphuric. They are available as castings, welding rod and standard mill forms that can be fabricated into chemical equipment such as tanks, autoclaves, heat exchangers and coils.

Table I. Principal Welding Features of Hastelloy Alloys

Hastelloy Alloy	Composition Per Cent.	Weldable Forms	Welding Process	Handling	Average Rockwell Hardness
A	Ni-57 Mo-20 Fe-20 Si-1, Mn-2 C-.15	Cast	O-A	HCl	B-92
		Wrought or Rolled	(1) M-A (2) O-A R		B-96
B	Ni-62·5 Mo-30 Fe-5 C-02-.12	Cast	O-A	Hot HCl	B-95
		Wrought or Rolled	(1) M-A (2) O-A R		B-98
C	Ni-Bal Mo-15 Cr-15 W-5 Fe-5 C-.04/.15	Wrought Cast	(1) O-A (2) M-A	Wet Cl_2	B-93
		Rolled	(1) M-A R		B-91
D	Ni-Bal Si-10 Cu-1 Al-1	Cast	O-A	H_2SO_4	C-52

O = Oxyacetylene A = Atomic Hydrogen
M = Metal arc R = Resistance

All four of these Hastelloy alloys are supplied in a variety of forms. Alloys A and B are supplied in the form of hot-rolled sheet and plate; forgings; welded tubing; welding rod (alloy B only); wire; and castings such as cast pipe, fittings, and valve and pump parts. Because these two alloys can be hot rolled and forged, they are fabricated into many kinds of equipment.

Hastelloy alloy C is available in hot-rolled sheet and plate but cannot be supplied in forgings or hot-rolled bars. Hastelloy alloy D is supplied in the form of castings only.

Hastelloy alloys A and B are also available in the form of drawn wire. Hastelloy alloy C has been drawn only experimentally into wire form.

The Hastelloy alloys are not available in clad sheet, although some experimental rolling has been done.

Hastelloy alloys can be readily fabricated by the same methods as those used for stainless steel, Monel and other high-alloy materials, however, these alloys require careful handling in order to avoid such conditions as cracking, and lessened corrosion resistance resulting from carbon pickup or improper heat treatment.

The uses of these alloys, Hastelloy alloys A and B—developed primarily for corrosion resistance to hydrochloric acid—also have resistance to sulphuric acid, phosphoric acid, acetic acid and many organic chemicals. Alloy A is for relatively low-temperature applications. Hastelloy alloy B can be used in handling all concentrations of hydrochloric acid at temperatures up to and including the boiling point.

Alloy C has been used for handling sulphuric acid, hydrochloric acid, mixtures of nitric and sulphuric acid, and especially for oxidising agents such as ferric chloride, cupric chloride, wet chlorine gas and organic chemicals.

Hastelloy alloy D is used chiefly for handling hot sulphuric acid, but it has good resistance to phosphoric, cold hydrochloric and many other acids.

Hastelloy alloys can be readily fabricated by oxyacetylene, atomic-hydrogen, Heliarc, resistance, automatic and metallic arc welding.

The physical properties of these alloys make careful technique as well as proper sequence of welding operations particularly important. In most cases, heat treatment is desirable so as not to impair the corrosion resistance.

The corrosion resistance properties are only developed after welding, by heat treatment. Heat treatment is not necessary when the equipment is to be exposed to mild forms of corrosion. Where corrosion is a particular problem, heat treatment is usually necessary.

In the welding of Hastelloy alloys A, B and C, it is most important that a neutral flame is maintained during welding to avoid carbon pickup. Atomic hydrogen and Heliarc welding have proved superior to the oxyacetylene welding process. It is desirable to preheat castings to a dull red heat before welding to avoid causing excessive stresses. Such practice should be followed by a full anneal of the material; because holding the alloys at red heat for any appreciable length of time impairs their corrosion resistance.

Very rarely is cracking trouble encountered in welding a Hastelloy alloy vessel. The possibility of cracking is much more likely in lining work.

Although cracking trouble in welding Hastelloy alloys is negligible and occurs only when care is not taken to avoid excessive stresses, the sequence of welding operations should be planned carefully. It is apparent that the material does not crack from the stresses after reaching room temperature, but it does crack when severely stressed at elevated temperatures.

In the wrought form, Hastelloy alloys A, B and C can generally be worked in the same manner in which stainless steel, Monel and other similar high alloys are fabricated. The strength of these materials at elevated temperatures and their hot-short properties in a range of 1200 deg. to 1800 deg. F. make the working somewhat more difficult. Fabrication techniques used for stainless steel can be adapted to Hastelloy alloys A, B and C, and these alloys can be formed, bent, deep-drawn, and spun, as well as welded.

The metallic-arc, atomic-hydrogen and oxyacetylene processes have all been used but the metallic-arc process is preferable using reversed polarity with a coated rod. Heavily coated electrodes of the same analysis as parent metal are recommended, although Hastelloy B electrodes can be used on Hastelloy A metal to secure better corrosion resistance. These alloys flow very well under the metallic arc, and form a good-looking weld with a nice cover bead and excellent penetration.

The most satisfactory all-round welding process for sheet and plate of Hastelloy alloys A, B and C is the metallic-arc process.

In arc welding Hastelloy alloys, it is recommended that the welding be done rapidly with as little current as possible; also, that the arc be choked short and the electrode be worked away from the molten puddle.

The principal difficulty with the atomic-hydrogen process for these alloys, is controlling the heat, to prevent overheating the weld metal and the areas adjacent to the weld.

Carbon pickup is particularly detrimental to Hastelloy C, because this alloy contains chromium and thus picks up carbon much more readily. Because of the physical characteristics of Hastelloy alloy D, the oxyacetylene process is the only suitable method for welding in ordinary production.

Molten alloy D, like cast iron, is quite fluid, so that a welding operator who knows how to weld cast iron should have little difficulty when welding Hastelloy alloy D.

All castings of Hastelloy D should be preheated to a temperature of approximately 1400 deg. F.

Welding with such gases as propane and hydrogen has been done, but with little advantage, if any, over the oxyacetylene or atomic-hydrogen processes.

The alloys will work harden quite rapidly as compared to stainless steel, and in general only approximately 50 per cent. of the working that is possible to perform on stainless steel can be done on Hastelloy alloys. In forming sheet or plate it is desirable to do most of the work cold. If hot working is performed it is essential that the work be carried out at temperatures above 1900 deg. F. to avoid cracking during the forming operations.

Only two of the standard heat treatments will be mentioned, "full anneal" and "stabilising anneal." On Hastelloy alloys A and B a "full anneal" consists of holding at a temperature of 2100 deg. to 2150 deg. F. for twenty minutes to one-and-a-half hours, and cooling rapidly in air or quenching heavy sections in water; for Hastelloy alloy C, the temperature is a little higher—2200 deg. to 2225 deg. F.—for two to three hours.

The stabilising anneal is used before welding A, B or C sheet to prevent deterioration adjacent to welds when heat treatment after welding is not practical. It is also used after welding to reduce the loss of corrosion resistance and toughness. This treatment is most effective when preceded by the full anneal. For alloys A and B, it consists of holding at a temperature between 1925 deg. and 1950 deg. F. for two to four hours and air cooling. Alloy C should be held for the same time at the temperature of 2050 deg. to 2075 deg. F. and also cooled in air.

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Printed in England by Lawrence Press Ltd., Henry Road, New Barnet, Herts